

## Valuing flexibility in time and space: Assessing the potential for demand-adaptive transit

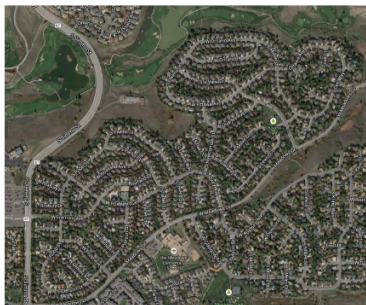
Charlotte Frei, PhD, EIT

March 1, 2017

# Outline

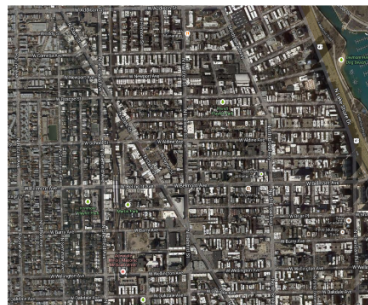
- 1 Background
- 2 Methodological Approach
  - Semi-Flexible Service Design
- 3 How Travelers Spend their Time
- 4 Stated Preference Survey
  - Choice Model Findings
- 5 Conclusions
- 6 Case Study Areas
  - South Jefferson County, Colorado
  - Joliet, Illinois

# Motivation: Public Transportation Provision in Low-Density Areas



Littleton, CO; Walk Score: 29

1000 ft  
400 m



Chicago, IL; Walk Score: 94

Source: Google Maps

**Figure:** Comparison of Street Connectivity in urban vs. suburban setting

- Vicious and virtuous cycles of regional transit allocation
- High-cost of demand-responsive transit, taxis
- Demographics: youth travel, silver tsunami; suburbanization of poverty, shared economy

# Demand-Responsive Transit Services

- Typically door-to-door unless some structure in place
- Sometimes a deadline (2 hours before, evening before), particularly for paratransit
- Most research focuses on different service combinations, meaningful objective functions, varying input parameters (e.g. time windows, vehicle types, zone size and coordination)





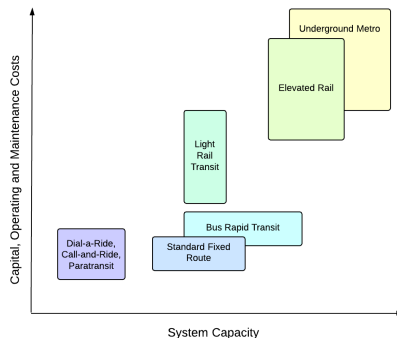
0001

# Literature Summary

- Methods for fixed service network design, e.g. Verbas & Mahmassani, 2014
- Substantial work on Dial-a-Ride problem, reviewed in e.g. Cordeau and Laporte, 2007, Berbeglia et al. 2010
- Limited work on hybrid/flexible service design:
  - path-building for hybrid services with many small vehicles: Jung & Jayakrishnan, 2014; Atasoy & Ben-Akiva, 2014;
  - On-demand transit: Speranza et al., 2016;
  - service design for hybrid services: Errico et al. 2011 and 2012;

# Problem Statement

How to design a desirable flexible service with multiple vehicles?

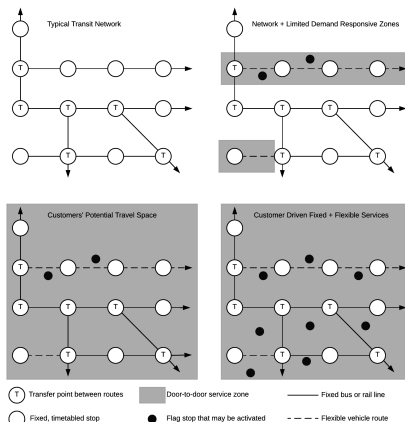


Adapted from Wright, 2004

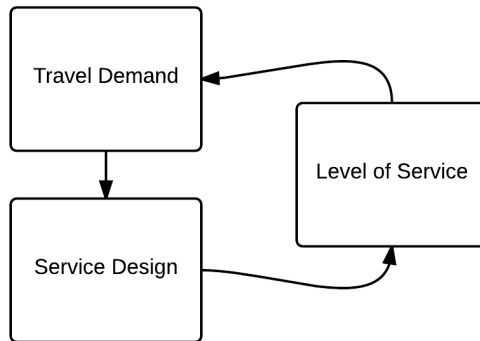
- How much structure is needed?
- What level of structure offers benefits to both users and operators, as compared to DRT or fixed-route?

# Existing Methods: Single-Line DAS or fleet of door-to-door vehicles

- Crainic et al. - single line, single vehicle on grid network with Euclidian distance; Speranza et al. 2016 fleet of shared taxis
- Some interesting practical examples exist, e.g. Flexlinjen in Sweden and Kutsuplus in Finland, but little knowledge of supply-demand interactions



# Conceptual Framework



# So how to find the right level of service and design?

Steps to define structured service:

- 1 Delineate service area
- 2 **Gather demand data**
- 3 Cluster demand to identify candidate compulsory stops
- 4 Simulate service with random demand in order to define skeleton schedule at compulsory stops

→ Conduct **behavioral studies** to understand features that are important to users.

## Time Use in Transit

- In practice, travel is generally considered a derived demand and unproductive use of time (Urry, 2006; Ory and Mokhtarian, 2005), but information and communication technology allows for greater flexibility in activity participation and time use.
- Desire for productivity and multitasking can affect activity mode, location and timing (Mokhtarian, Saloman and Handy, 2006)
- Some passengers desire devices for “shielding” self from strangers (Lofland, 1970; Gottdiener, 2001)

# April 2010 Survey of Time Use

- Observation on board CTA trains (N=400):
  - Line/station
  - Time of day
  - Temporal stability of activities
  - Seated vs standing, crowding
- Qualitative survey on-line (N=336)
  - Self-selection
  - Trip characteristics
  - Rider characteristics
  - Activities
  - Attitudes

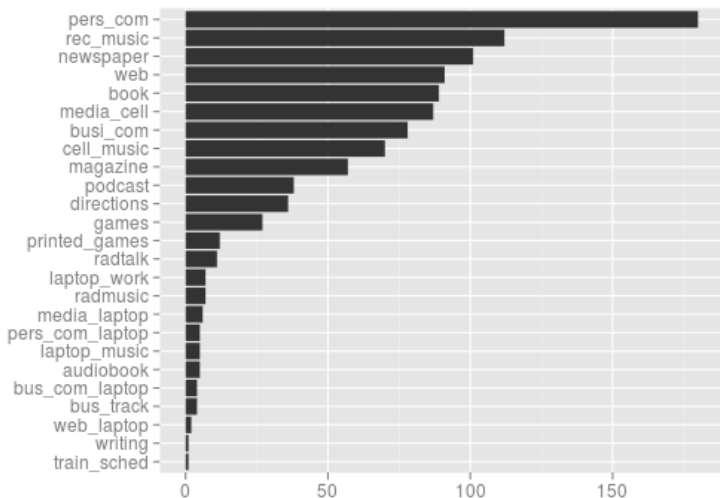


# 2010 Survey of Time Use



Figure: Survey Respondent Recruitment Assistant

# 2010 Survey of Time Use



## Satisfaction related to activities on board

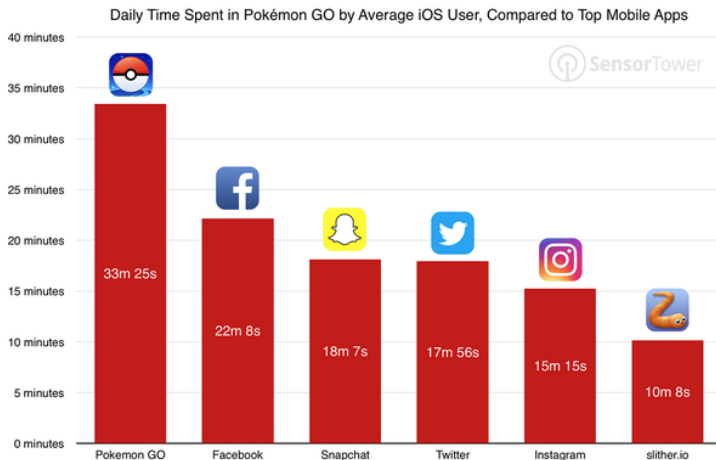
- Work activities and “active leisure” activities (such as reading) resulted in higher satisfaction than “passive leisure” activities like listening to music
- Total number of activities conducted was associated with...
  - lower satisfaction for people who listened to music/podcasts or used their phones,
  - but higher satisfaction for people who played games.
  - Total number of activities not significant for passengers who read books, newspapers, etc.
- Satisfaction combined with use of music/phones suggest these are tools for privatizing public space
- Satisfaction with service and attitude toward productive use of time are clearly related, regardless of activity

## What about now?

- April 3, 2010 was release of first iPad.
- Observed my fellow passengers for 4 days during morning commute:
  - SMALL SAMPLE, but...
  - Roughly same number using phone, headphones (50% and 30%)
  - Fewer reading books (30% in 2010 versus 11% now)

Headphones	Phone	Book	No object	Total
13	26	6	8	56 passengers
25%	49%	11%	15%	100%

# What about now?



Based on U.S. iOS usage for July 11, 2016.

Source: Sensor Tower

# Desirable Service Features

- CTA market research suggests flexibility, reliability and sense of familiarity most important (Abt SRBI 2009)
- Market research for Denver RTD (2011) suggests
  - users **motivated by** environmental benefits, avoiding traffic, and saving wear-and-tear on car
  - on-time performance, value of service, availability of information, and wait time at transfers most **influence satisfaction**
- Koppelman and Lyon (1981) Schaumburg Dial-a-Ride Study: perceptions of reliability, convenience and safety most impact on desirability of DAR.
- Frei et al. (2015) find that how CTA customers use time affects rating of the service
- Forest Transit Lines (2017) suggests 86% of customers OK with a 5-minute wait when they order (so timeliness not as critical as reliability when information available)

# Survey Design

- Convenience sample of Chicago area commuters:
  - CMAP newsletter (thanks, CMAP!)
  - NUTC Facebook and Twitter accounts
  - Personal Facebook and Twitter accounts
  - **Urban** (78%) and suburban (16%) respondents
- Short-, medium- and long-commute markets to generate different attribute levels for efficient design
  - Maximizes information obtained from each respondent, and choices presented are more realistic
  - Gathered information about actual commute and revealed preference to classify respondents





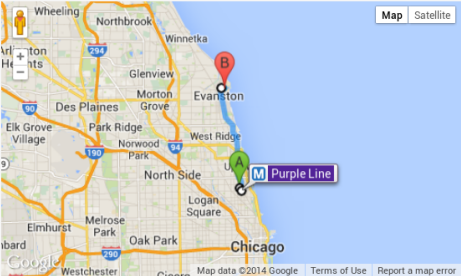
# Web-based, dynamic survey

Survey captured current reliability by asking the user to report their **actual** travel time (ATT) for transit and/or auto, compared to Google API generated result, and rate how confident they were in on-time arrival given their reported **allowed** time:

How many minutes does your transit work commute take?

For your given start and end location, Google Maps suggests the following time and distance:

Distance: 9.0 mi  
Time: 39 mins



My transit commute typically takes:  minutes

# Weather Scenarios

- The two possible weather scenarios in the winter (February 2015) were:
  - Good weather: “Assume the temperature is in the low 30s Fahrenheit (0 Celsius) and it is sunny.”
  - Bad weather: “Assume the temperature is approximately 5 Fahrenheit (-15 Celsius) and there is accumulated snow and ice on the ground.”
- The two possible weather scenarios in the summer (August-September 2014) were:
  - Good weather: “Assume the temperature is in the mid-70s and it is sunny.”
  - Bad weather: “Assume the temperature is in the mid-50s and there is a light rain.”



# Mode Choice Model

- Mixed Logit Model Structure
  - Random Parameters: in-vehicle travel time, access time, cost
  - Captured correlation between responses from same individual
    - Each respondent completed 6+ stated choice experiments
- Model Parameters
  - Modal attributes from stated choice experiments
    - in-vehicle travel time and access time treated as modal-specific
  - Current commute mode(s)
    - Binary variables indicating whether or not respondent commutes with given mode 2+ times per week
  - Demographics
  - Season and Weather
  - In-vehicle activities

# Seasonal and Weather Effects- MNL Models for each season and pooled samples

- Wait time more significant and valued roughly twice as much in winter than summer
- Value of travel time: \$21/hr for flexible or car; \$19/hr for transit
- Access time and frequency have similar magnitude across all seasons and weather conditions, and all highly significant
  - Depending on model structure, **walk time** valued 30-50% more than travel time (\$25-\$30/hr)
  - Wait time at home: \$10.1 per hour
- Bad weather
  - Increased probability of choosing flexible transit in both summer and winter
- Respondents who had used TNC service in past less likely to choose traditional transit in summer
- Bike and carshare program participants more likely to choose transit modes, this effect was more significant among bikesharers

# Transit Vehicle Headway

Increasing magnitude and significance of respondent aversion to long headways in simple MNL models segmented by season

Vehicle Headway	Extra Minutes of car IVTT compared to 0-5 minute headway
12-15 minutes	4.1
20-25 minutes	10.5
30 minutes	17.2
60+ minutes	22.3

# Model Results- Other Parameters 1/2

- Enthusiastic (or altruistic?) Survey Respondents
  - Survey respondents that chose to answer more than the required 6 stated choice experiments were more likely to choose flex and conventional transit
- Employer Reimbursement
  - Respondents that do not receive any reimbursement from their employer for travel expenses were more likely to choose flex and conventional transit
  - Reimbursement included pre-tax benefits, parking space, company car etc.

# Model Results- Other Parameters 2/2

- Car Ownership
  - Respondents that do not currently have a car available for commuting were more likely to choose car over flex and conventional transit in the stated choice experiments
  - Real vs. perceived costs? Problem with SP vs. RP data?
    - Autonomous vehicles - operating costs versus ownership costs
- Gym Bag
  - Respondents that typically bring a gym bag to work were significantly less likely to choose flex and conventional transit



## Example with User Generalized Cost Function



# Example with User Generalized Cost Function

Cost to wait at home until next feasible insertion in a demand-adaptive system:  $User\ Cost = \beta_{wait_{home}} \times wait_{home} + \beta_{IVTT} \times IVTT$

Cost to walk to bus stop .25 miles from home:

$$User\ Cost = \beta_{wait_{station}} \times wait_{station} + \beta_{walk} \times walk + \beta_{IVTT} \times IVTT$$

# Example with User Generalized Cost Function

Given

- wait at home valued around half of IVTT,
- wait at station valued double IVTT,
- access time valued 30% more than IVTT,
- a walk speed of 3 mi/hr, and
- assuming travel time not affected by detour:

Cost to wait at home until next feasible insertion:

$$\text{User Cost} = .5 \times Y \text{ min wait} + 1 \times 10 \text{ min TT}$$

Cost to walk to the compulsory stop .25 miles from home:

$$\text{User Cost} = 2 \times 2 \text{ min wait} + 1.3 \times 6 \text{ min walk} + 1 \times 10 \text{ min TT}$$

Thus, Y could be as high as **24 minutes** and a user with this cost function may choose to wait at home.

Future work could test sensitivity of user and operator cost functions.

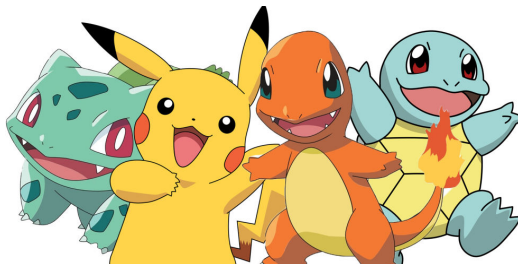
# Summary

- Higher value of access time compared to travel time suggests flexible modes could provide a better user experience
  - Adding structure to a demand-responsive service may reduce (perceived) barriers to entry for people accustomed to a traditional transit service, since current transit users have some wariness of hypothetical flexible mode
  - Time use on board suggests passengers can be more accepting once they are on their way: transfers, reliability, access and wait time are more onerous than in-vehicle time
- Could test service designs with combined regional travel survey data (to the extent available) as well as data on boarding and alightings in service areas to identify potential structures that would:
  - attract greater ridership
  - reduce operating costs in lower-density areas
- Longer-term question: How to better capture individual and community value to allocate funds for various needs? How we allocate time and space?

# Q&A

## Acknowledgements:

- CMAP assisted in online survey distribution
- Co-authors Hani S. Mahmassani and Michael Hyland (Northwestern University)
- Wight & Company
- Denver RTD, DemandTrans provided data



# References

- [1] Crainic, T. and et al. (2005). Meta-Heuristics for a class of demand responsive transit systems. *INFORMS Journal on Computing*, 17(1):10–24.
- [2] Crainic, T. G., Errico, F., Malucelli, F., and Nonato, M. (2010). Designing the master schedule for demand-adaptive transit systems. *Annals of Operations Research*, 194(1):151–166.
- [3] Errico, F., Crainic, T. G., Malucelli, F., and Nonato, M. (2011a). The design problem for Single-Line demand- adaptive transit systems. Technical Report 2011-65.
- [4] Errico, F., Crainic, T. G., Malucelli, F., and Nonato, M. (2011b). A unifying framework and review of Semi-Flexible transit systems. Technical Report 2011-64, CIRRELT.
- [5] Errico, F., Crainic, T. G., Malucelli, F., and Nonato, M. (2012). A benders decomposition approach for the symmetric TSP with generalized latency. Technical Report 2012-78, CIRRELT.
- [6] Errico, F., Crainic, T. G., Malucelli, F., and Nonato, M. (2013). A survey on planning semi-flexible transit systems: Methodological issues and a unifying framework. *Transportation Research Part C: Emerging Technologies*, 36:324–338.

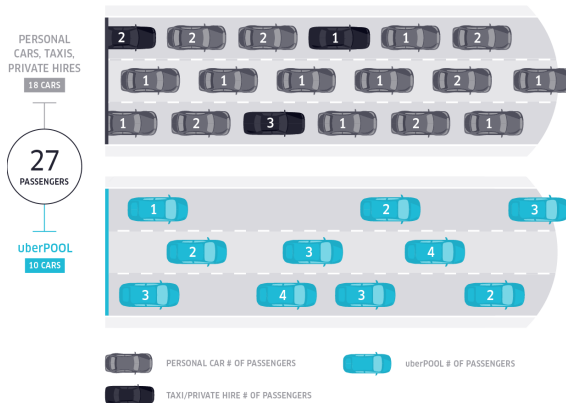


# Simulation Procedure

- Typical DRT service objective function is to maximize slack time in the schedule, sometimes subject to every customer's time window.
- Optimization: minimize sum of operator and user cost and impose a large penalty for time window violations
  - 50 simulations per hour for 4 consecutive hours in the morning peak
- Simulate service in three rounds
  - Initial simulation: no time windows, random demand
  - Second round: fix time windows identified from initial round (confidence level: 90%)
  - Third round: add random demand at compulsory stops

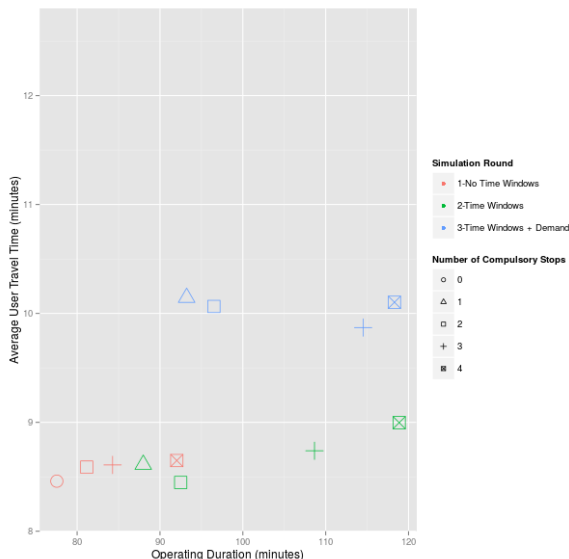


# A Comment on Emerging and Existing Flexible Modes

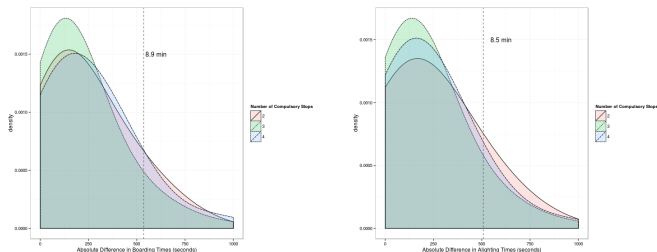


- How will cities and agencies work with these platforms to improve service, potentially with their existing rolling stock?
- Will these services be low-cost enough to serve current captive markets?
- What is the role of car-sharing (and autonomous shared vehicles) in filling this gap?

## User Travel Time vs. Operator Cost for Fleet Size = 3



# Passenger Delay when Random Demand is Introduced



(a) Absolute Difference in Boarding Times (b) Absolute Difference in Alighting Times

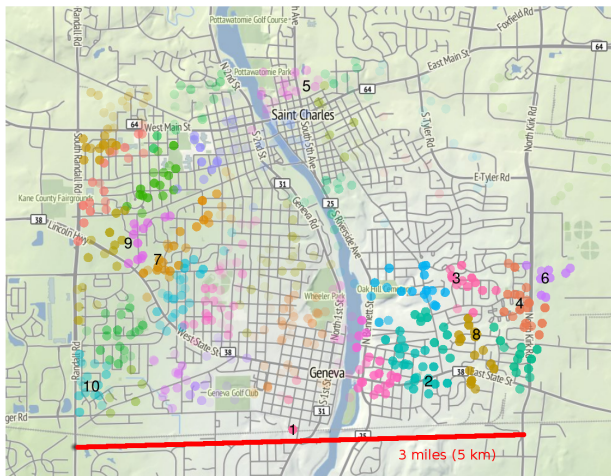
**Figure:** Difference in Boarding and Alighting times after Additional Demand at Compulsory Stops with Time Windows

# Assessment of Appropriate Candidate “Checkpoints”- Another example



Request Type ● Compulsory ● Destination ● Origin

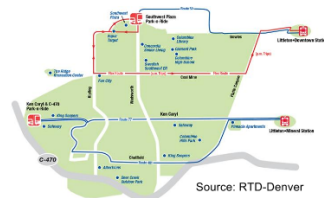
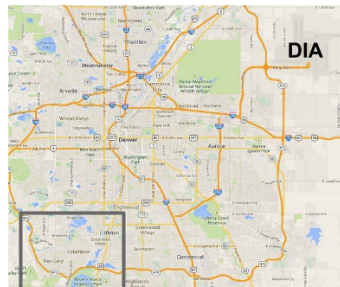
## Flexible Technique: St. Charles, Illinois, USA (Chicago metro area)



# Case Study Service Area Information

## Census Fact Finder 2012 Estimates:

- Population: 42,000
- Current trip requests: ~5-10 per hour (off-peak/peak)
- Service Area: 16 square miles
- Median income: \$57,330
- Employment:
  - 33,000 over age 16
  - ~22,000 in labor force
  - 7.4% unemployment
  - Lockheed Martin employs 14,000



South Jefferson County, Colorado

# Applied to Existing Service Area

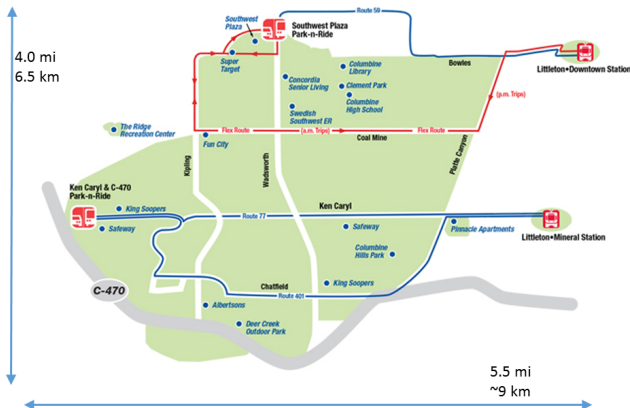


Figure: South Jefferson County Call-and-Ride Area

South Jefferson County, Colorado

# Clustering and Network Analysis

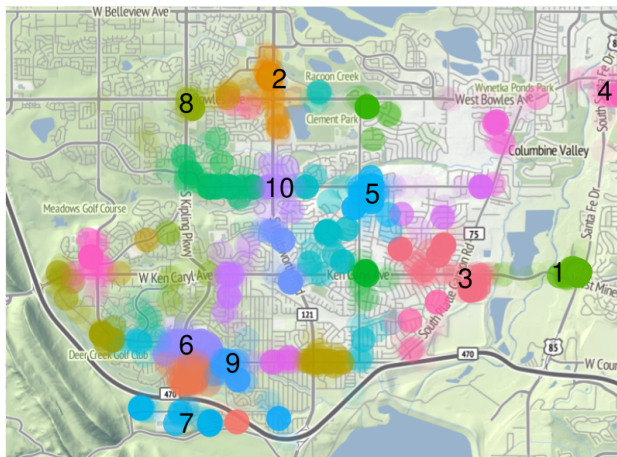


Figure: K-means Clustering with Clusters of highest degree labeled



South Jefferson County, Colorado

# Bird's Eye View of Location 6/7

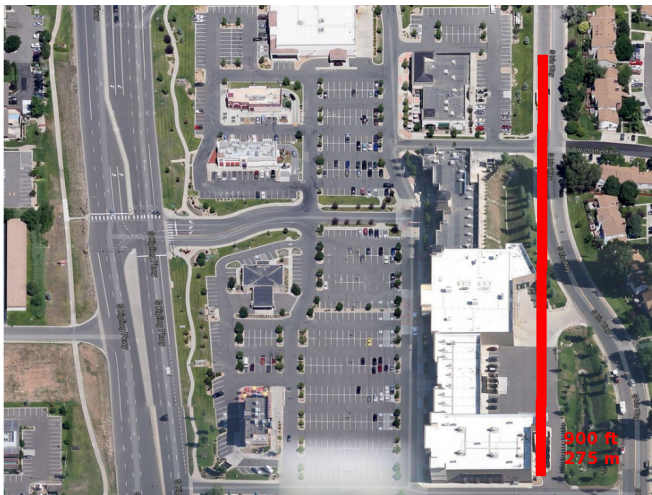
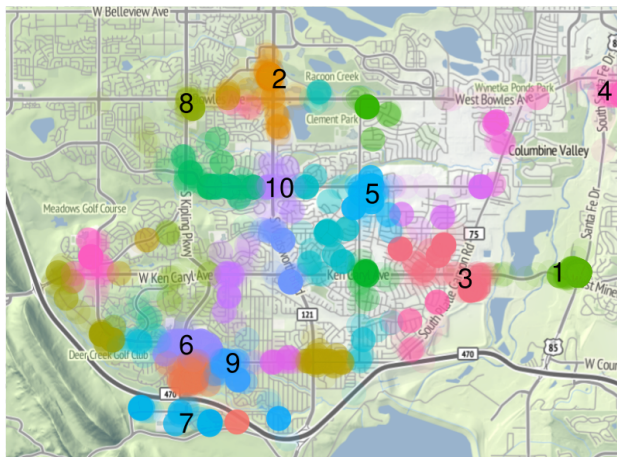


Figure: Bird's Eye View of Kipling Ave. & W Chatfield Ave.

South Jefferson County, Colorado

# Candidates tested: 1, 2, 4 and 6

Selection reflects planners' judgment or a formal location model (e.g. coverage, access time)



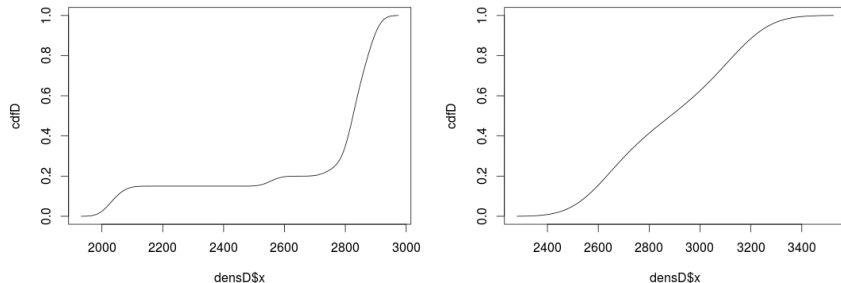
# Optimization Procedure

- Objective function:

$$\min\{(1 - \alpha) * \textit{OperatingCost} + \alpha * \textit{UserCost}\}$$

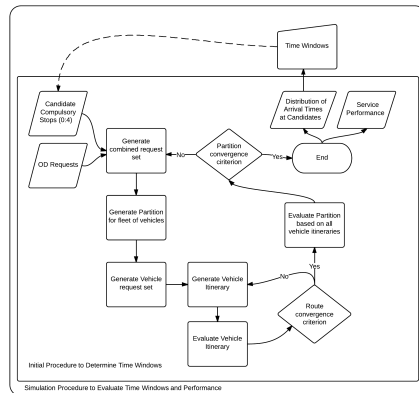
- With one vehicle, pick-up and delivery problem with time windows (PDPTW).
- With multiple vehicles- MV-PDPTW:
  - Must assign partition of requests to each vehicle and solve traveling salesman problem for each vehicle in the fleet.
  - Mutate routes and partitions until find optimal solution
- Repeat optimization for different realizations of demand to get distribution of arrival times at candidate compulsory stops
- Distribution of arrival times informs time windows at compulsory stops
- In contrast to DAR problem (where everyone may have a time window), only compulsory stops have time windows for strategic planning

# Distribution of Arrival time at Candidate Compulsory Stops



**Figure:** Example Cumulative Distribution Functions for arrival time at candidate stops for optimized routes

# Identifying Time Windows for Compulsory Stops



- Simulate service without time windows (i.e. earliest arrival and latest departure from a "checkpoint"), but with compulsory stops, to determine ideal time for visiting.
- Then add time windows to simulation to assess performance.

# Distribution of arrival defines end of time window

Compulsory Stops	Fleet	Map #: Compulsory Stop	Mean Arrival (Minutes after t=0)	SD(Arrival)	90th Percentile
1	1	1: Mineral LR Station	48.38	30.14	85.60
1	2	1: Mineral LR Station	22.06	16.62	44.97
1	3	1: Mineral LR Station	16.02	10.57	30.12
:	:	:	:	:	:
4	2	2: Southwest Plaza	15.66	16.25	40.83
4	2	1: Mineral LR Station	21.49	13.09	36.65
4	2	6: Mixed Retail/Residential	30.21	22.39	56.59
4	2	4: Downtown LR Station	30.86	20.28	55.92
4	3	2: Southwest Plaza	8.74	9.41	22.49
4	3	1: Mineral LR Station	12.24	10.66	24.73
4	3	6: Mixed Retail/Residential	21.27	18.25	44.28
4	3	4: Downtown LR Station	25.75	16.84	46.30

South Jefferson County, Colorado

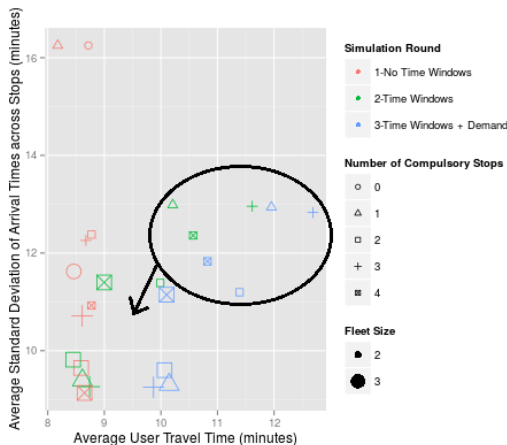
# Example Route Candidate “Checkpoints”



Request Type ● Compulsory ● Destination ● Origin

**Figure:** South Jefferson County, Colorado: Potential Last mile connector, 3 compulsory stops, 2 vehicles

# Predictable Service with more vehicles



- As you add vehicles and compulsory stops, arrival times at any point in service area are generally more predictable